JPL 26 Meter Automation Project

Christopher W. Stevens

Honeywell Technology Solutions Inc.
7515 Mission Drive
Lanham, MD 20706-2291
Christopher.Stevens@honeywell-tsi.com

Norman L. Baker

Honeywell Technology Solutions Inc.
under contract to CSOC
2500 E. Foothill Blvd.
Pasadena, CA 91107-3464
nbaker@jgld.gdscc.nasa.gov

1 ABSTRACT

The basic concept of the 26 Meter Automation Project was to provide an operational capability as autonomous and automatic as possible. This was to be accomplished through significant use of existing components and Commercial-Off-The-Shelf (COTS) capabilities and to reduce implementation costs.

Wonderware InTouch was the platform selected for the Man Machine Interface (MMI). This platform provided an intuitive language, which enabled quick Graphical User Interface (GUI) development and Supervisory Control and Data Acquisition (SCADA), as well as the ability to provide full autonomous operation.

Descartes Systems Science Inc. OmniServe was selected for rapid machine interface development for Serial and IP connections for the various types of equipment.

Wonderware InTouch and OmniServe selections allowed the re-use of the existing MBR RF-Subsystem Controller software that significantly reduced development time.

Microsoft C++ was used to interface the 7-Day Schedule, Sequence of Events, monitor data blocks, audible station notifications and file maintenance functions. Visual Basic and TCL/TK based tools ensure support product integrity.

Existing components selected for upgrade required interface changes from the legacy JPL DSS Monitor and Control subsystem (DMC) to the new 26-Meter Monitor and Control Processor (MCP). New equipment was introduced which replaced and/or complemented the system and enabled the MCP full monitor and control.

The 26 Meter operations architecture required two types of machines. The MCP, which interfaces with the equipment at the DSS, and a Remote User Interface (RUI), which provides remote monitor and control via the MCP. While the MCP controls equipment from the systems level, the MCP operations interface can be set to monitor only and remote the equipment control to the SPC RUI. Several other RUI machines are placed offsite for monitoring purposes. Any RUI is capable of monitoring any MCP, regardless of the site.

Maintenance calibrations have been automated. This has reduced the calibration time and eliminated the operator intensive manual process.

The operational methodology allows both manual and autonomous operations. Both types have assumed the “Load and Go” pre-track scenario. This required the use of several support product files containing project information, configuration files, calibration history files, Nominal Sequence of Events (NSOE), DSMS 7-Day Schedules, Telemetry and Command Processor (TCP) configuration files (desktops) and Override Sequence of Events (OSOE). The benefits of this approach are that stations have increased spacecraft contact opportunities, reduction of the required operations knowledge base, reduction the training time to qualify operators, and minimizing the risk of configuration procedural errors.

In both the manual and autonomous operations, the MCP assumes the responsibility of personnel and equipment safety, configuring the equipment with “Closed Loop Control”, acquiring the spacecraft, and maintaining receiver lock throughout the pass. Automation performs the other functions via the NSOE or OSOE keywords. Manual operation requires an operator to perform all other functions via the GUI in accordance with POCC using the nominal SOE as a guideline.

Through the use of COTS platforms and the combined talents of Systems Engineers and Operations Engineers, the 26 Meter Automation Project has been successfully implemented on a moderate budget.

2 INTRODUCTION

The basic concept of the 26 Meter Antenna Automation Project was to provide an operational monitor and control capability as autonomous and automatic as possible. This was to be accomplished through significant use of existing components and Commercial-Off-The-Shelf (COTS) capabilities and to reduce implementation costs.

Formerly, the 26 Meter antenna was supported by a legacy control system which required a series of operator type-ins that initiated a single action. Multiple type-ins were required to perform a function. Furthermore, there were limited scripting capabilities, where the operator could perform a series of actions from a single type-in. Most scripting capabilities were not based on closed loop equipment status. Monitoring of equipment required the operator to interrogate individual subsystems to determine system status.

3 PLATFORM

Wonderware InTouch, which runs under Windows NT 4.0, was the platform selected for the Man Machine Interface (MMI). This platform provided an intuitive language, which enabled quick Graphical User Interface (GUI) development and Supervisory Control and Data Acquisition (SCADA), as well as the ability to provide full autonomous operation.

Perhaps more significant that the graphical interfacing capabilities of Wonderware InTouch is the ability to run scripts (which are similar to BASIC in syntax) based on either a single variable changing state (a data change script) or if a certain condition exists (condition script.)

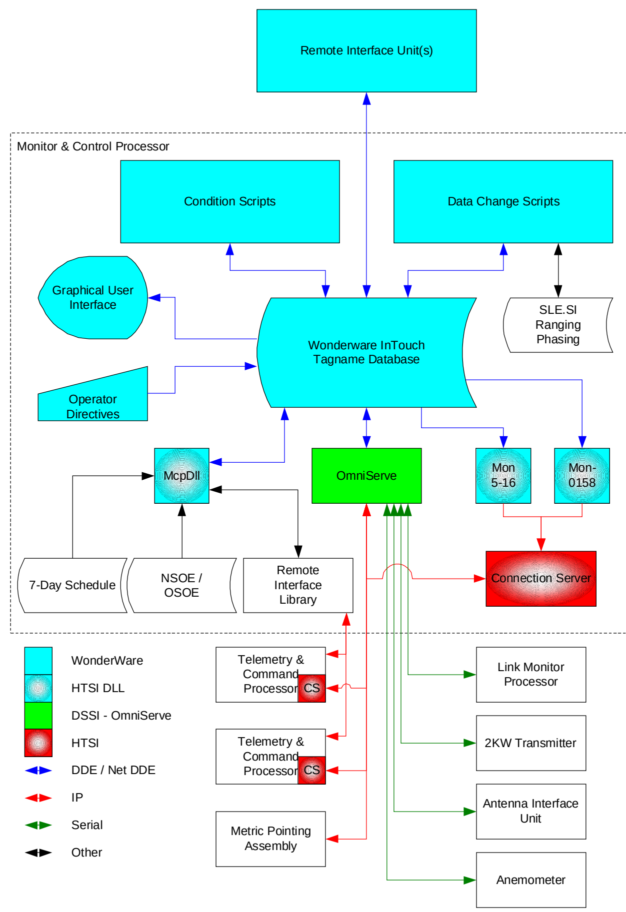
Variables inside InTouch are contained in Tags. These tags can be a variety of data types, including integers, reals, strings, and discretes. Indirect variables also exist allowing the programmer to easily execute a variety of functions by changing the indirection of a variable. This ability is used extensively in MCP's closed loop control scripts.

The most important attribute of these tags is the ability to directly interface to the external world. Communications are accomplished in two ways; the tag can specifically reference an external Dynamic Data Exchange (DDE) device or an external program can access the tagname database directly via DDE.

The MCP commonly uses data change scripts for many tasks. The simplest example is translating a numeric tag into a string. A more complex example is the implementation of a state machine that controls the loading, polling, status updates, and unloading of external devices.

Condition scripts are a very powerful feature of InTouch. Condition scripts can be used to detect anomalous conditions, such as a receiver going out of lock, and triggering corrective actions like opening the receiver loop bandwidth. The MCP frequently uses condition scripts to push a state machine from one state to the next.

Condition scripts can be used to create a system approaching an expert system. Expertise is captured in a series of condition scripts that take actions based upon a set of existing conditions, which then attempt to rectify the condition. The MCP is not truly an AI system however, since it contains no inference engine and it cannot determine the next steps to take outside what has been programmed into the condition scripts.



4 EQUIPMENT INTERFACE

OmniServe (Descartes Systems Science Inc.) was used to communicate to the equipment. Wonderware InTouch provides the data to be sent to the equipment, and OmniServe handles the formatting, error handling, and the low-level interface for both serial and IP devices. One of the most unique functions of OmniServe is the ability to accept unsolicited messages and, based upon pre-determined formats, parse the message, and pass the message back into InTouch via DDE variables.

One of the developed protocols parsed a re-directed screen dump into 146 separate variables. This protocol was developed in less than a week.

5 SOFTWARE RE-USE

Wonderware InTouch and OmniServe selections allowed the re-use of the existing MBR RF-Subsystem Controller software that significantly reduced development time.

The 26 Meter Automation project saved development time by using the existing I/O from the MILA-Bermuda Re-engineering Project's RF-Subsystem Controller. The user interface was re-developed to mimic the NMC look and feel, but the underlying interfacing was used which saved many months of development. The old user interface is still available via maintenance level functions.

Another re-use of software was the Connection Server. Initially developed to interface the Telemetry and Command Processor to the RNS, the software was re-used to transport MON 5-16 and MON-0158 monitor blocks from the MCP to the RNS.

6 ADDITIONAL LANGUAGES USED

Microsoft C and C++ were used to interface the telemetry control processor (TCP), 7-Day Schedule, Sequence of Events, monitor data blocks, audible station notifications and provide file maintenance functions.

Wonderware InTouch allows C subroutines to be called via dynamically-linked libraries (DLLs). A C library was developed which allows the MCP to quickly read the 7-day schedule and the sequence of events, which are at the heart of the automation system.

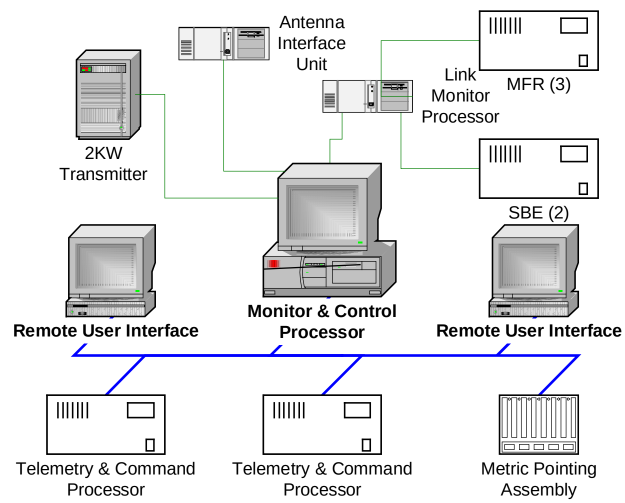
C libraries were also developed to generate MON 5-16 and MON-0158 monitor blocks. These monitor blocks are then passed to the RNS via the Connection Server, a program originally developed to interface the TCP to the RNS.

Avtec provided a Remote Interface Library (RIL), an API, as the primary control method of their PTP system. The largest C library developed was used to interface the MCP to the TCP via the RIL. This C library is responsible for loading and unloading desktops (TCP configuration tables), as well as collecting status for the operator displays and monitor blocks. This library is also responsible for updating various parameters in the TCP's SFDU blocks.

Operator directives, which may control multiple functions, are pre-processed by the MCP then passed onto the library for final processing.

7 UPDATED EQUIPMENT

Existing components selected for upgrade required interface changes from the legacy JPL DSS Monitor and Control subsystem (DMC) to the new 26-Meter Monitor and Control Processor (MCP). New equipment was introduced which replaced and/or complemented the system and enabled the MCP full monitor and control.



The Telemetry and Control Processors (2) replace the aging Telemetry and Command System. Based upon the Avtec PTP, the TCP can process Viterbi or convolutionally encoded telemetry, and has the capability to directly accept an SLE (Space Link Extension) uplink.

The Antenna Interface Unit (AIU) was upgraded to replace aging equipment and to provide monitoring capabilities via the MCP.

Metric Pointing Assembly (MPA) modifications allow SRA displays to be redirected to the MCP for complete closed loop control.

The Link Monitor Processor (LMP) was updated to allow control via the MCP.

A 2KW transmitter was added to provide redundancy and to allow automated configuration of the 26 Meter system.

An anemometer was added to monitor wind speed. This capability allows the MCP to safe the station based upon high (average or instantaneous) wind speed conditions.

8 OPERATIONAL ARCHITECTURE

The 26 Meter operations architecture required two types of machines. The MCP, which interfaces with the equipment at the DSS, and a Remote User Interface

(RUI), which provides remote monitor and control via the MCP. While the MCP controls equipment from the systems level, the MCP operations interface can be set to monitor only and remote the equipment control to the SPC RUI. Several other RUI machines are placed offsite for monitoring purposes. Any RUI is capable of monitoring any MCP, regardless of the site.

The communications overhead between RUI and MCP is low. Only items that have changed are send to the RUI, and when the RUI is required to generate a configuration change, a single DDE variable is set which triggers a series of actions in the MCP, i.e. all the processing is done at the MCP. The communications overhead is so low that similar systems that have been developed may be controlled over a dial-up connection.

9 OPERATIONS METHODOLOGY

The operational methodology allows both manual and autonomous operations. Both types have assumed the "Load and Go" pre-track scenario. This required the use of several support product files containing project information, configuration files, calibration history files, Nominal Sequence of Events (NSOE), DSMS 7-Day Schedules, Telemetry and Command Processor (TCP) configuration files (desktops) and Override Sequence of Events (OSOE). The benefits of this approach are that stations have increased spacecraft contact opportunities, reduction of the required operations knowledge base, reduction the training time to qualify operators, and minimizing the risk of configuration procedural errors.

In both the manual and autonomous operations, the MCP assumes the responsibility of personnel and equipment safety, configuring the equipment with "Closed Loop Control", acquiring the spacecraft, and maintaining receiver lock throughout the pass. Automation performs the other functions via the NSOE or OSOE keywords. Manual operation requires an operator to perform all other functions via the GUI in accordance with POCC using the nominal SOE as a guideline.

Because the MCP is used at multiple sites (Goldstone, CA; Madrid, Spain; Canberra, Australia), it was designed to allow site personnel to update the status of the equipment as well as configure site unique parameters, such as collimation tower location, nominal range delays, and telemetry time-tagging offsets.

10 CONFIGURATION

The station hardware configuration agreed upon by JPL and Honeywell was designed to simplify the task of automation and was in direct contrast to the 34 Meter and 70 Meter configuration methodologies. The 26 Meter tracking subnet was to be spun off into its own station centric, stand-alone entity. This requisite prompted another Honeywell development of an automated Support Product Provider (SPP) that found re-use in the Deep Space Network schema.

The hardware configuration consists of three Multi-Function Receivers (MFR), two S-Band Exciters (SBE), two transmitters (2KW automated as prime and 20KW manual control as backup), two Telemetry Command Processors (Avtec TCP), and two types of ranging systems (tone and sequential). The first telemetry and command link, comprised of MFR1, SBE1, and TCP1 were to be hardwired as the coherent link to provide Doppler and ranging. MFR2, SBE2, and TCP2 were hardwired as the backup non-coherent link. The third MFR is dedicated to the Acquisition Aid.

The 26 Meter operational design methodologies were developed taking in account manual and fully autonomous operations. Support configuration scenarios were deemed void of calibration activities. Calibrations were to be previously performed and calibration information stored in files for recall. Equipment configuration was to be 'Close Loop Control' and as automated as possible. Five types of spacecraft acquisition were addressed. The acquisitions were defined as Non-coherent, Blind, 1-Way, 2-Way, and 3-Way. Each acquisition scenario applied to High Earth Orbiters (HEO), Lunar Orbiters (LUN) and two different conditions for Low Earth Orbiters (LEO). First condition is hot acquisition where the antenna is above transmitter limits for spacecraft intercept. The second condition is cold acquisition below the transmitter limit with the ability to initiate the uplink when transmitter limit has been cleared.

A 26 Meter Sequence of Events Keyword Dictionary was developed for autonomous operations. The 26 Meter equipment and operations differ vastly from the 34/70 Meter rendering that Keyword Dictionary unusable. The 26 Meter Keyword Dictionary was later updated to include configuration information in human readable format to accommodate manual operations.

11 SAFETY

The Monitor and Control Processor (MCP) was also tasked with personnel and equipment safety. In compliance, the MCP makes Public Announcements before antenna movement or transmitter radiation during ranging calibration. This interface was accomplished by two methods, based upon the public announcement capabilities of the station. For stations that allow a public announcement via a telephone dial-in connection, the

MCP announces via the Dialogic Proline/2V telephone interface. For stations that require a keyed microphone, a Programmable Logic Controller (PLC) closes the key, and the announcement is played over the sound card interface.

Should an objection be made to the announcement, an operator may press the "Stop Automation" button at any time.

The MCP checks for antenna run-away during phasing calibration. The MCP also detects high wind conditions and automatically stows the antenna. At this point, automation is suspended and operator intervention is required to move the antenna back to point when the wind subsides.

12 MAINTENANCE

Maintenance methodology was to accommodate calibrations either launched automatically from the DSMS 7-Day Schedule or initiated by operations and to be conducted from a list of supported projects. When manually invoked, calibrations can be performed on a project-by-project basis as well. The manual option provides the capability to phase individual receivers including the Acquisition Aid receiver or both main antenna receivers simultaneously.

Supported projects were to be added and removed dynamically and to share configuration Receiver Exciter Ranging (RER) preset information whenever possible. The MCP was to contain no hard coding for individual projects.

13 SCHEDULING

The DSMS 7-Day tracking schedule was considered re-usable without modification. All parameters in the schedule were defined and supplied to the task for parser development to extract the information necessary to conduct an automated pass. Except for the TCP, the file naming convention was designed around building all required files names from the tracking schedule. A Mission Control/Configuration Table (MCT) was developed to include all required information to configure the station for support. A suite of Visual Basic software tools was developed to integrate responsibilities within the JPL/DSN Operation & Engineering organization and create dependable support products. The first of three tools were developed for the Network Operations Project Engineer (NOPE) to develop/modify a date stamped INFormation file. This tool also generates a separate file that the NOPE can use to cut and paste equipment configuration information into a Network Briefing Message. The INFormation file is delivered to the Table Analyst Engineer. The analyst inputs the file into the second tool that controls and assigns the RER preset number, generates the MCT file and all other files for maintenance and dynamic project configuration. This tool also outputs a report of all spacecraft and pertinent information that 26 Meter subnet supports. The third tool is an MCT Viewer that helps station personnel to check the actual station settings against the intended configuration. The parallel effort developing the SPP assumed the responsibility to generate a web based TCL/TK tool for projects to modify Nominal Sequence of Events (NSOE) and create a pass specific Override Sequence of Events (OSOE) when the nominal support is altered. This web-based tool was modified for stand-alone PC operation to allow the NOPEs to develop NSOEs with proper format, syntax, and line identification.

14 OPERATOR INTERFACE

All subsystems pass streams of variables, or monitor data, to the MCP. All displays are programmed in the MCP. This enables GUI development to toggle, input, or select virtually all parameters in the system. This has reduced the required operational knowledge base from the use of legacy operator directives. This approach has also enabled the generation of functional displays as opposed to subsystem displays. I.e. A display for initiating calibration or track support, a display to perform all tracking functions and a display for monitoring overall station performance and data delivery.

The 'Closed Loop Control' has significantly reduced calibration and configuration time. Phasing the MFRs to a frequency only take about two and a half minutes whether it's one or both MFRs once the antenna is pointed at the Collimation Tower. Ranging calibration time has also been reduced. The MCP can perform sequential steps immediately following the successful completion of the previous step. Once the operator has started the calibration process, he/she is not required to monitor the progress. These automated procedures have eliminated the operator intensive work that has often taken multiple operators to perform.

15 REDUCTION OF PRE-TRACK / POST-TRACK TIME

When the MCP configures for support, all configuration parameters are verified within two minutes. The MCP keeps track of significant events and sends a Post-pass summary for posting at the End of Track (EOT). These two functions have allowed JPL/Pasadena Operations to qualify a reduction in time from Beginning of Activity (BOA) to Beginning of Track (BOT) and from EOT to End of Activity (EOA).

The Tracking Data Relay Satellite (TDRS) project levied an additional requirement. A special emergency function was programmed into the MCP to assist projects with spacecraft recovery in the event of a flat spin. After initially configuring for the event, a graphical icon will cause the MCP to initiate a tune to acquire spacecraft immediately followed by the execution of an emergency command. The MCP has consistently demonstrated this sequence within six seconds.

16 TRAINING

The comprehensive 26 Meter training package is web based. The training material was developed using screen capture from the MCP, TCP, and the support product tools. The material is laid out in an outline format for easy retrieval. The outline topics are hyperlinked to the individual presentations. Each presentation has on page step-by-step instructions. The training package contains all aspects of the 26-Meter sub-net.

17 LESSONS LEARNED

Have all supporting entities in place and as thoroughly tested as the automated product itself.

The initial 26 Meter Automation delivery had most of the functionality. All efforts were focused on test and transfer of the system to operations. However, the Support Product infrastructure was not in place. Some support products were generated by the test team during development and were not qualified for operations. The system was removed from operations until the support products were developed and tested. The reputation of the system had been severely damaged. When everything was functioning properly and the system placed back into operations, the operators still maintained their distrust in the system.

18 PROBLEMS ENCOUNTERED

One of the biggest problems is that the MCP development took place on opposite sides of the United States. When viewing the program, it essentially lists the titles of the scripts or subroutines but not the date modified. Work began on the same initial code; one developer modifying the automation routines while the other was working on manual routines. The changes were documented in the developer's notebook. When it came time to integrate the two software packages, some of the modified scripts were inadvertently overlooked. To overcome this obstacle, the developers coded a do-nothing script where all code changes were documented.

The diversity of the developers also led to the code not being integrated as well as it could have been between automation and manual control.

Another problem encountered stems from a requirement of having only one display for the tracking station. Operators were use to a four head workstation that the MCP was tasked to replace. Several attempts were made to overcome this display real-estate obstacle. The first attempt was to switch to larger monitors. We have designed multiple functionalized subsystem displays that give the operators enough information and control to ensure there are no problems without displaying the larger subsystem windows.

The major programming challenge was developing a close loop control interface for the Sequential Ranging Assembly (SRA). The legacy interface to the SRA is via a captive LAN from the Metric Pointing Assembly (MPA). The SRA configuration operator directives pass through the MPA. The SRA passed display information through the MPA to the legacy Link Monitor and Control (LMC) subsystem while only passing tracking data information to the MPA. This new interface was engineered to have the MPA pass the SRA display information to the MCP. OmniServe was configured to parse the display information as a monitor data stream to obtain all configuration parameters.

19 REALIZED BENEFITS

The MCP GUI and expert system-like programming has reduced the required operator knowledge base. This interface also reduces training time to qualify new operators. The automated functions reduce calibration and configuration time, which increases spacecraft contact opportunities. The 'Close Loop' configuration control has eliminated configuration errors as well as operator intensive processes. The system design is very dynamic for adding and removing spacecraft that are supported. The approach of configuring the system with information contained in the 7-Day schedule has eliminated the need for manually generated cross-reference tables (S/C name – S/C# - Preset) and problems caused by misreading them.

20 REFERENCES

Functional Requirements Document / Functional Design Document for the 26 Meter Automation Project; Release 01, Revision 04: April 3, 2000; Document Number: 26M.FRDFDD.01.04.000403

21 ACKNOWLEDGEMENTS

As with any project of this magnitude, there was an enormous amount of background work and assistance by many key individuals. We feel compelled to acknowledge their contributions to the success of this project.